Chapter 5: EMF Health Risk Model

5.1 Representation of Uncertainties

The approach described in Chapter 4 provides exposure calculation results for different exposure measures. The actual health risks depend on the mitigation measure chosen and the resolution of four uncertainties:

- whether EMF poses a hazard
- which exposure measure is responsible, if there is a hazard
- how serious the health effect is

Figure 5.1 shows these uncertainties in a decision tree. The uncertainty about whether EMF exposure poses a hazard was modeled directly by assessing a probability p(Hazard). By hazard we mean that exposure to EMFs leads to health effects that are large enough to be detectable by epidemiological studies (i.e., risk ratios in the neighborhood of 1.5 to 2). The uncertainty about about exposure measures was modeled by assigning probabilities to the seven exposure measures described in chapter 4. Alternatively, the user could specify one exposure measure by assigning it a probability of one. The uncertainty about the risk ratio was not captured by a probability distribution, but rather was left to a user choice or a sensitivity analysis. The risk ratio was, in fact, a key parameter of the dose-response function as described below.

In practice, most analyses were conducted by fixing an exposure measure and then conducting a two-way sensitivity analysis on the probability of a hazard (p) and the risk ratio (RR). This sensitivity analysis identified the preferred alternative for each combination of p and RR.

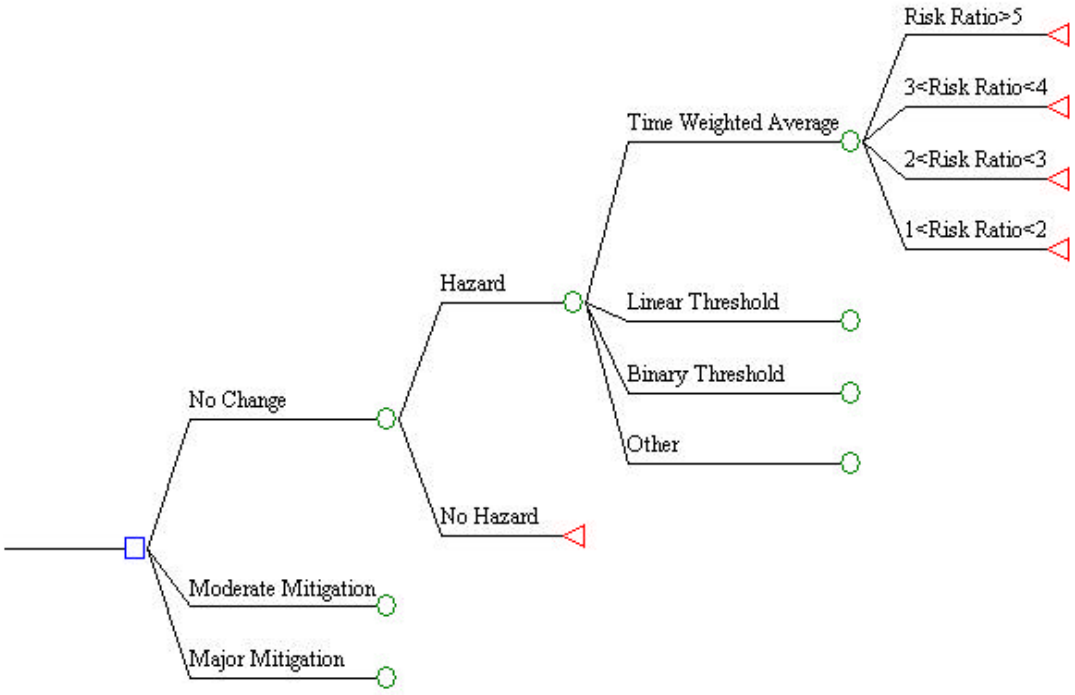

Figure 5.1: Decision Tree Characterizing Uncertainty about a Possible EMF-Health Link

(The square denotes a decision node, circles denote event nodes, and triangles denote end nodes at which consequences can be determined. Branches that end with a circle are completed by the tree above them.)

5.2 Dose-Response Functions

The dose-response functions are not treated as uncertainties, but rather as user-specified inputs. All dose response functions are either linear or piece-wise linear in the respective dose measure. The "response" in the dose-response function is defined as the risk ratio – the ratio of the rate of health effects of people exposed to EMFs at a given dose divided by the rate of health effects of people not exposed to EMFs.

Consider the simplest case of a TWA dose without a threshold (Figure 5.2). In this case, the risk ratio at zero exposure should be 1. To determine the slope of the dose-response function, we need one more point. Some epidemiological studies find increased risk at fields as low as 2 mG. But what is the likely risk ratio at that level, assuming that EMF poses a health hazard? In the illustration, we assume that the risk ratio at 2 mG doubles the risk at zero mG (RR=2). This gives two points of the dose-response function

1. Exposure=0 mG, Risk Ratio=1

2. Exposure=2 mG, Risk Ratio=2

These two points completely define the dose-response function as a straight line with a slope of 2.

There is a problem, however, with the assumption that the risk ratio increases linearly with the dose. For example, if one applies the dose-response function in Figure 5.2 to exposures of electric powerline workers, which can be around 1,000 mG, the risk ratio would be approximately 100. If this were true, line workers would show a clearly observable excess mortality. But even the most pessimistic estimates of risk ratios for line workers are closer to 2 to 5. Moreover, even the most studied and proven hazards like smoking show risk ratios that are at most 10 or 20. To be realistic, one therefore needs to consider either one of two options:

- decrease the slope of the dose-response function substantially, e.g. to 1.2 at 2 mG or

- put a ceiling on the risk ratio.

We chose the more conservative second solution. Thus, in addition to specifying the slope and the intercept of the dose-response function, the user needs to define the maximum risk ratio. Figure 5.3 shows an example.

The discussion above was illustrative of the TWA effects function with a dose defined in milliGauss units. For linear threshold effects functions, the dose is also defined in milliGauss units. However, for linear threshold dose measure, all exposures below the threshold are treated as "zero," when estimating the dose. For example, if a people are exposed to fields of less than 2 mG 50% of the time and, and 3 mG for the other 50% of the time, their 2 mG linear threshold exposure would be 1.5 mG and their 5 mG linear threshold exposure would be zero. While the exposure calculations for the

linear threshold models are different, the dose-response function, as exemplified in Figure 5.3, stays the same.

In the case of binary threshold effects functions, the exposure is calculated in percent of time that the threshold is exceeded (Figure 5.4). The x-axis of the dose-response functions is the dose expressed in percent, with a risk ratio of 1 at zero percent. By defining one other point (for example, a risk ratio of 2 at 20 percent exceedance of a 2 mG threshold), the user can define the slope of this dose-response function. As in the TWA and linear threshold models, the user can also define a maximum risk ratio.

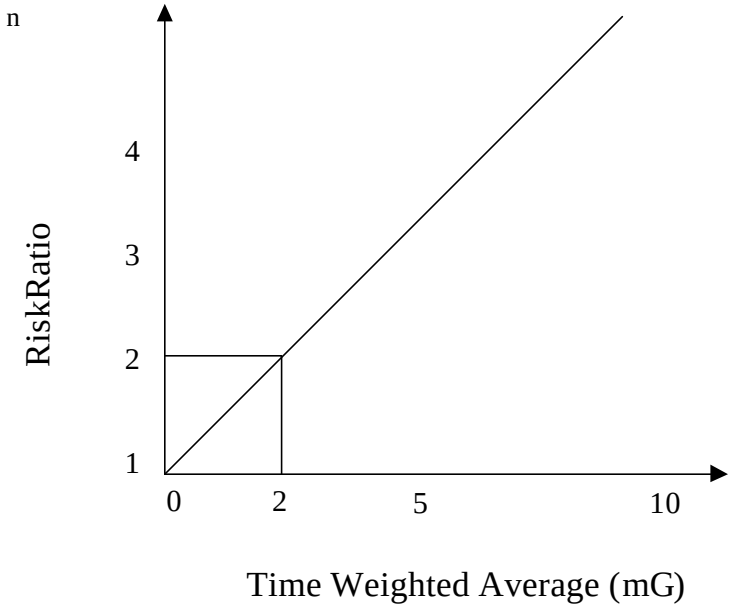

Figure 5.2: Example of a Linear Dose-Response Function for the TWA Effects Function (No Ceiling)

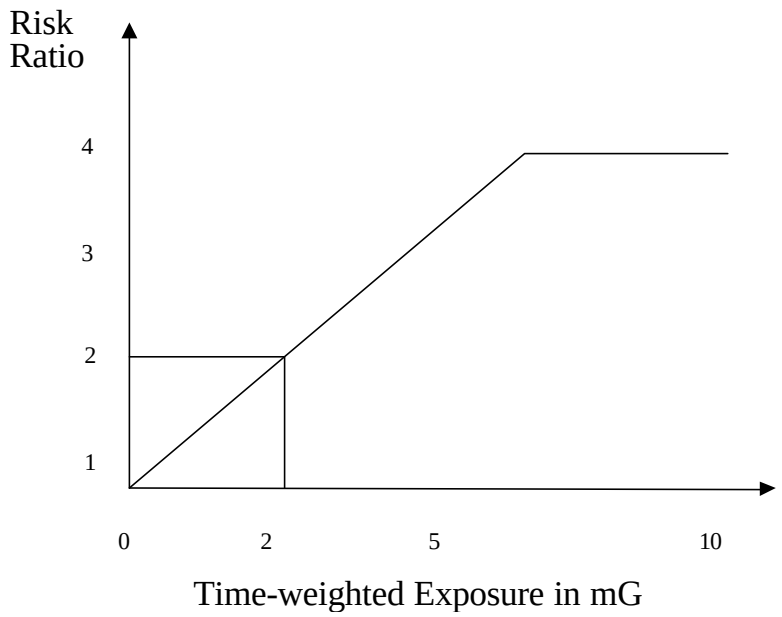

Figure 5.3: Example of a Linear Dose-Response Function for the TWA Effects Function (with a Ceiling a Risk Ratio of 4)

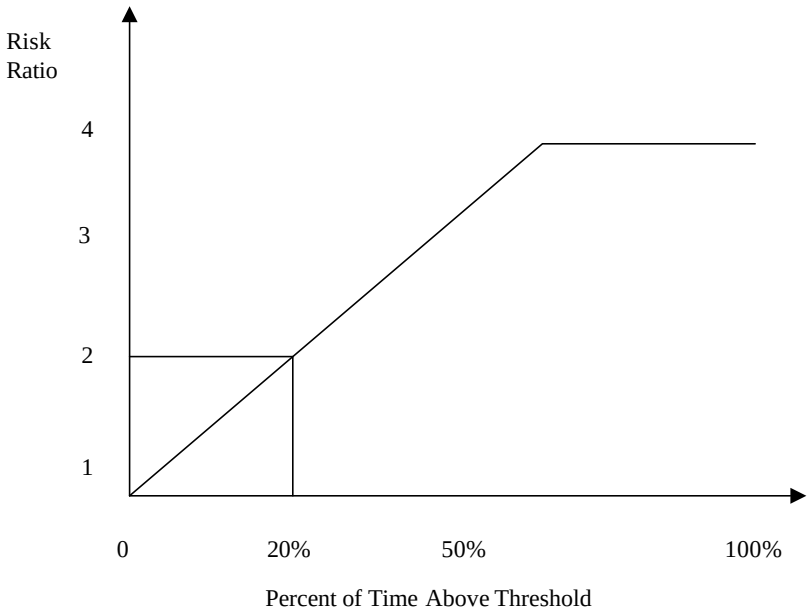

Figure 5.4: Example of a Binary Threshold Dose-Response Functions (Threshold at 2 mG and Ceiling a Risk Ratio of 4)

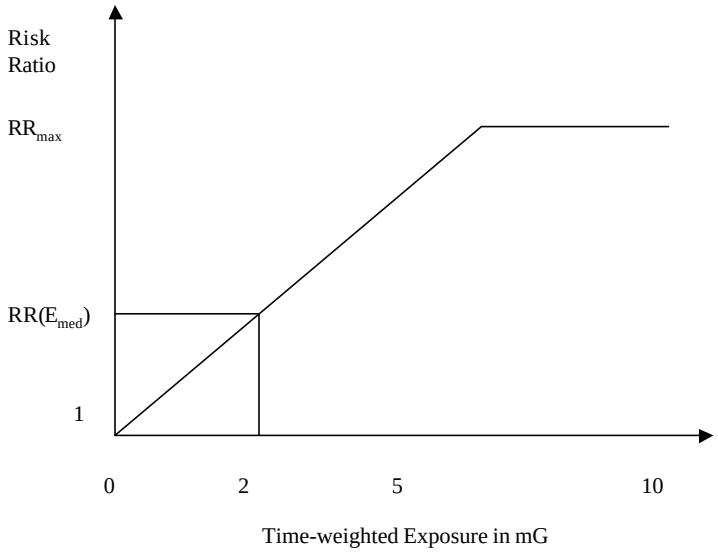

Figure 5.5: Parameterization of the TWA and Linear Threshold Dose-Response Functions

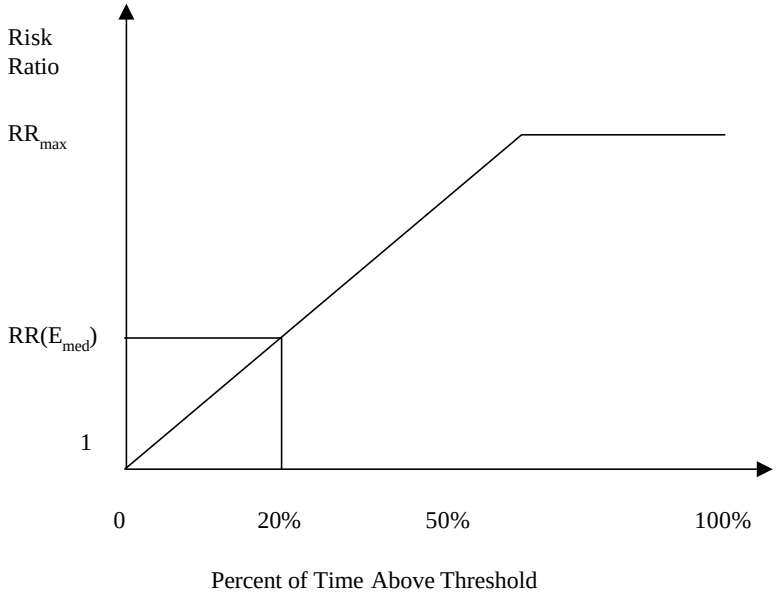

Figure 5.6: Parameterization of the Binary Threshold Dose-Response Function (2 mG)

Figures 5.5 and 5.6 generalize these numerical examples by defining variables (parameters) for the values of the dose-response function. In both types of exposure measures, the user specifies, separately for each health endpoint, a medium exposure, E_{med}, typically a level at which epidemiological research has shown elevated risks. For TWA and linear thresholds, a possible starting point for E_{med} would be 2 mG, because some epidemiological studies have shown associations with disease above that level. For the 2 mG binary threshold, a possible starting point would be 50% of the time above 2 mG, etc. In addition, the user has to define the risk ratio RR at E_{med}. A reasonable starting point for most health endpoints might be a risk ratio

of 2 for the E_{med} values above. Note that the selection of E_{med} and RR(Emed) have to be consistent with the epidemiological research findings. For example, setting RR(2mG)=20 would not be justified by the literature for any health endpoint. The user's third choice is the definition of the maximum risk ratio RR_{max}. A starting point would be the high-end risk ratios found in the epidemiological literature.

The risk ratio at E_{med} should be interpreted as the ratio of the rate of health effects of people exposed to E_{med} divided by the rate of health effects of people without any EMF exposure. Since people are exposed to EMFs everywhere, this is a very difficult number to estimate, since a part of the base rate is possibly due to EMF exposure. To deal with this issue, we developed a method to correct the published base rates for their possible attributable EMF risk from everyday exposure (see section 5.4).

5.3 Choice of the Parameters of the Dose-Response Function

In the analyses presented in chapter 8, we will vary RR_{med} from 1 to 5 to explore the whole range of dose-response functions. As a default, the analyses use RR_{max}=5. The default settings of the models are shown in Tables 5.1 and 5.2

Table 5.1: Default Values for the Dose-Response Function (TWA and Linear Thresholds)

Health Endpoint	Emed	RR(Emed)	RRmax
Alzheimer's Disease	2 mG	2	5
Adult Brain Cancer	2 mG	2	5
Adult Leukemia	2 mG	2	5
Adult Breast Cancer	2 mG	2	5
Childhood Leukemia	2 mG	2	5
Childhood Brain Cancer	2 mG	2	5

Notes:
E_{med} stands for a medium exposure at which health effects might be observed
$RR(E_{med})$ stands for the risk ratio at the medium exposure
RR_{max} stands for the maximum risk ratio

Table 5.2: Default Values for the Dose-Response Function (Binary Thresholds)

Health Endpoint	BT at 2 mG	Emed BT at 5 mG	BT at 10 mG	RR(Emed)	RRmax
Alzheimer's Disease	50%	20%	10%	2	5
Adult Brain Cancer	50%	20%	10%	2	5
Adult Leukemia	50%	20%	10%	2	5
Adult Breast Cancer	50%	20%	10%	2	5
Childhood Leukemia	50%	20%	10%	2	5
Childhood Brain Cancer	50%	20%	10%	2	5

Notes:
E_{med} stands for a medium exposure at which health effects might be observed
$RR(E_{med})$ stands for the risk ratio at the medium exposure
RR_{max} stands for the maximum risk

5.4 Base Rates

To calculate the incremental risk (IR) of an individual or a population, one needs to know both the risk ratio (RR) and the annual base rate (BR) for the health end point under consideration. With these ingredients the incremental risk at an exposure E can be calculated as

$$IR(E)= RR(E)*BR - BR.$$

The expected loss of life expectancy that corresponds to this incremental risk is

$$ELL=IR(E)*LE,$$

where LE stands for life expectancy. Both base rates and life expectancies are highly age specific. We therefore used data on age specific base rates and combined it with data on age specific life expectancy and data on the distribution of ages to calculate:

$$ELL = \Sigma\ p_i*[RR(E)*BR_i-BR_i]*LE_i,$$

Where p_i is the percentage of people in age group i, BR_i is the base rate of the cancer mortality or incidence under consideration, and LE_i is the life expectancy at age group i. For children, we calculated ELL for age groups up to 19 years. For Alzheimer's disease, we only considered age groups above 65 years. Breast cancer rates are for females only. All data come from the California Cancer Registry and the Statistical Abstracts of the United States. Table 5.3 shows the age specific mortality and incidence rates and Table 5.4 shows the life expectancies at different age groups.

The estimate of Alzheimer's disease was a special case, since there are only very few age-specific estimates of the mortality or incidence rates for this disease. The

Alzheimer's Association reports prevalence of 3% for people aged 65 to 74, 10% for people aged 75 to 84, and 47% for people 85 years or older (Alzheimer's Association, 1998). Herbert et al. (1995) and Kawas et al. (2000) found that the annual incidence is between a small fraction of a percent among people in their early sixties and 6-8% among people older than 85. To obtain a better estimate of the incidence rate of Alzheimer's disease, we constructed a model that fitted the incidence rate for various age group the available prevalence estimates for these age groups. This model gave a reasonable good fit at an incidence rate of 0.5% or 500 cases per year in 100,000 people above 65 years old. Because the incidence rate is so much higher than the mortality rate, and because the effect of Alzheimer's is primarily the deterioration of the last years of a person's life, the project only analyzed Alzheimer's incidence.

We recently added base rates for heart disease to the Analytica model. Using these base rates and the "Other" category for health endpoints, the user can explore the effect of including heart disease on the model results.

The base rates in Table 5.3 include the attributable risk due to EMF, if EMF exposure poses a significant hazard. Thus, if one wants to estimate the incremental risk for exposed vs. unexposed people, the base rates for unexposed people have to be reduced by the amount attributable to EMF. As DelPizzo (see Apendix H)) points out, the base rate correction will need to be more severe, when the assumed is ratio is high. For example, for a risk ratio of 2 at 2 mG, the attributable risk due to background exposure from EMFs is about 37%, for a risk ratio of 3 it is about 60%. We used DelPizzo's calculations of attributable risk due to background EMF exposure to adjust our base rates (see Appendix H).

This problem is less serious in the case of the binary or linear threshold models, especially for higher thresholds. Most exposures above these thresholds are rare and will occur from specific sources such as powerlines, not from background. For example Zafanella (1993) estimates that only some 2.5% of homes in the U.S. have elevated fields above 2 mG, mostly due to net currents in home grounding systems. Thus, it is not unreasonable to assume that background exposure below thresholds of 2, 5, or 10 mG do not contribute substantially to the attributable risk. Therfore, we have applied DelPizzo's base rate corrections only to the TWA calculations.

Table 5.3: Age Specific Mortality and Morbidity Rates[1]

	Brain Cancer		Breast Cancer		Leukemia	
Age	Incidence	Mortality	Incidence	Mortality	Incidence	Mortality
0-4	3.6	1.0	0.0	0.0	7.5	1.1
5-9	2.8	0.9	0.0	0.0	4.3	1.5
10-14	2.3	0.8	0.0	0.0	2.9	1.4
15-19	1.9	0.6	0.1	0.0	2.9	1.5
20-24	1.9	0.6	1.2	0.1	2.2	1.4
25-29	2.8	0.9	7.3	0.9	2.3	1.3
30-34	3.5	1.3	23.9	3.9	3.0	1.7
35-39	3.7	2.0	56.7	10.0	3.2	1.9
40-44	4.7	3.0	114.0	21.1	5.0	2.7
45-49	6.1	4.3	193.0	36.1	6.4	3.6
50-54	8.9	7.3	228.0	51.9	9.9	5.4
55-59	11.1	8.9	267.0	65.8	14.7	8.4
60-64	13.1	11.7	329.0	78.5	22.3	14.0
65-69	18.2	15.3	401.0	96.2	30.1	20.3
70-74	21.2	18.1	447.0	114.0	43.7	30.9
75-79	22.9	20.1	475.0	130.0	56.4	43.6
80-84	20.9	19.0	458.0	146.0	71.3	59.2
85+	14.2	13.4	386.0	168.0	82.4	71.9
All Ages	**5.9**	**4**	**114**	**27.8**	**10**	**6.4**

[1]Source: California Cancer Registry, www.ccrcal.org, 2000. Data are averages for the years from 1989 to 1993, breast cancer rates are for females only

Table 5.4: Age Specific Life Expectancies[1]

Age Group	Total	Male	Female
0-4	74.1	70.7	77.5
5-9	69.2	65.7	72.6
10-14	64.3	60.8	67.6
15-19	59.4	56.0	62.7
20-24	54.7	51.5	57.9
25-29	50.0	46.9	53.0
30-34	45.3	42.3	48.3
35-39	40.7	37.8	43.4
40-44	36.1	33.4	38.7
45-49	31.6	29.0	34.1
50-54	27.3	24.7	29.5
55-59	23.2	20.8	25.3
60-64	19.4	17.1	21.2
65-69	17.2	15.1	19.0
70-74	13.9	12.0	15.3
75-79	10.9	9.4	12.0
80-84	8.3	7.1	9.0
85+	6.1	5.2	6.4

[1]Source: Statistical Abstract of the United States, 1994.